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3D mixed micromechanics-FEM modeling of piezoresistive carbon nanotube smart concrete

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Highlights

- The 3D piezoresistivity matrix of CNT-reinforced smart concrete is obtained
- Strain sensitivity is studied by a mixed micromechanics-FEM approach
- Arbitrary 3D strain conditions are incorporated in the micromechanics model
- CNT-reinforced smart concrete three-dimensional structural elements are studied

Abstract

Within the novel approach for structural health monitoring of civil engineering structures based on smart self-sensing structural materials, Carbon NanoTube (CNT)-reinforced cement-based composites, often termed "smart concretes", have drawn rising interest. These composites exhibit self-sensing capabilities resulting in measurable variations of their electrical properties under applied mechanical deformations. This, along with the similarity between these composites and conventional structural concrete, makes it possible to devise cost-efficient distributed monitoring systems for large-scale Reinforced Concrete (RC) structures. While several papers in the literature have focused on pilot applications of smart concrete strain sensors embedded into large RC components, the response of these sensors is not yet fully understood at the fundamental physical level and, as a consequence, their output is not properly interpreted. In order to shed some light on this issue, previous work by the authors focused on laterally unconstrained uni-axial loading conditions. This work extends the previous studies by presenting a mixed micromechanics and finite element approach for the analysis of CNT-reinforced composites subjected to arbitrary strain states. The two mechanisms that contribute to the electrical conductivity of CNT-reinforced composites, namely electron hopping and conductive networking, are contemplated within a percolation framework in the micromechanics model. On the basis of the micromechanics model, the 3D piezoresistivity matrix is determined, for the first time in the literature, by means of virtual dilation and distortion tests. Afterwards, the electro-mechanical modeling of three-dimensional composite elements is conducted by a multi-physics finite element code. The potential of the presented approach is illustrated by extensive parametric analyses, as well as a comparison against experimental data, including application of the mixed micromechanics-finite-element multi-physics formulation for electro-mechanical modeling of three-dimensional elements.

Keywords: Carbon nanotube, Cement-based composites, Micromechanics, Piezoresistivity, Smart concrete, Structual Health Monitoring

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1. Introduction

The recent development of novel multifunctional and smart structural materials, such as smart concretes and smart bricks, has led to a paradigm shift in the realm of structural health monitoring (SHM) of civil engineering structures towards self-sensing and self-inspecting buildings. In this new context, structural elements not only fulfill a structural function, but also behave as sensors apt for condition-based maintenance [1]. Carbon NanoTube (CNT) cement-based composites, often termed "smart concretes", have been shown particularly promising in the field of civil engineering with a broad spectrum of potential applications in the form of high-strength cement-based

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